Ocean Reference Stations

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Project Summary

The goal of this project is to maintain long-term surface moorings, known as Ocean Reference Stations, as part of the integrated ocean observing system. The scientific rational for these Ocean Reference Stations is to collect long time series of accurate observations of surface meteorology, air-sea fluxes, and upper ocean variability in regions of key interest to climate studies and to use those data to quantify air-sea exchanges of heat, freshwater, and momentum, to describe upper ocean variability and describe the local response to atmospheric forcing, to motivate and guide improvement to atmospheric, oceanic, and coupled models, to calibrate and guide improvement to remote sensing products and capabilities, and to provide anchor point for the development of new, basin scale fields of the air-sea fluxes. Model, satellite, and climatological fields of surface meteorology and air-sea fluxes have large errors; high quality, in-situ time series are the essential data needed to improve our understanding of atmosphere-ocean coupling and to build more accurate global fields of air-sea fluxes. Prediction and analysis of climate variability based on model or other products that have large errors in their atmosphere-ocean exchanges of heat, freshwater, and momentum is flawed; this effort to collect the critical in-situ flux time series and related efforts to develop air-sea flux products that use these Ocean Reference Stations as anchor points aim to remedy these flaws and greatly improve our understanding of how the atmosphere and ocean are coupled and together influence climate.

This project is now maintaining three Ocean Reference Stations at key locations: a site at 20°S, 85°W under the stratus cloud deck off northern Chile (Stratus), the Northwest Tropical Atlantic Station (NTAS) at 15°N, 51°W, and a site north of Hawaii near the Hawaii Ocean Timeseries (HOT) site. The surface buoys are equipped with Air-Sea Interaction Meteorology (ASIMET) systems developed at WHOI and capable of climate-quality measurements once per minute for one year. Telemetered near-real time data are provided to numerical weather prediction centers (but not included in their model runs, thus providing an independent means to examine model performance); these data are used to investigate model errors and biases and test improvements to the models. Data are also provided to validate remote sensing products and to guide development of new flux products. In addition, these data support research done by NOAA and other climate studies and these Ocean Reference Stations are coordinated with other flux reference sites. The Stratus Ocean Reference Station has proved to be a provider of key benchmark time series for examining atmospheric, coupled, and oceanic model performance in the important but challenging marine stratus region of the eastern tropical Pacific. The NTAS site is being upgraded as the prototype of implementation of real time telemetry of upper ocean data and coincident reporting of both surface flux and upper ocean heat content variability and anomalies.

Accomplishments

The project is managed as four Tasks, with accomplishments reported by task.

Task I: Engineering, oversight and data:

All three sites are now occupied by the modular-hull buoy (Fig. I-1). Hourly meteorological data are transmitted in near-real time via Argos telemetry and made available on an FTP server and a website with download capability. Data processing continues on schedule. The “best” quality meteorological and flux data is being made accessible through the web, typically within a year of recovery. New engineering and capability upgrades are being implemented and evaluated now at Stratus and at NTAS. In October 2007 an NDBC surface wave sensing and telemetry (Iridium) system was deployed on the Stratus buoy. In early 2007, the NTAS mooring was deployed with new hardware to permit telemetry of upper ocean data from instruments on the mooring line.

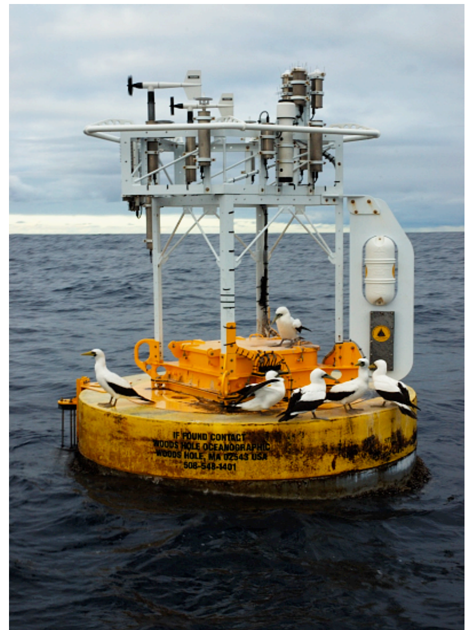

Figure I-1: The new modular buoy in use at all Ocean Reference Stations. Photo taken during the 2006 Stratus deployment and recovery cruise.

Task II: Stratus Site:

The stratus surface mooring was originally deployed in October 2000. It has been annually redeployed and recovered since that time, including the most recent done during the October 9-November 8, 2007 cruise of the NOAA Ship *Ronald H. Brown*. Accurate prediction of cloud amount and cover in marine stratus regions has long been a challenge; this is true off Peru and northern Chile. Further, model studies point to the dependence of the coupled climate variability of the Pacific Basin and surrounding continents to the atmosphere-ocean coupling in the stratus region. Thus, establishment and maintenance of an Ocean Reference Station in this critical but data sparse area has been a high priority.

Data recovery this year was good, post-calibrations are being done, and data files have been shared with colleagues. On the buoy we measure air temperature, sea surface temperature, relative humidity, incoming shortwave and longwave radiation, wind speed and direction, rain rate, and barometric pressure. On the mooring line the instrumentation is concentrated in the upper 300m and measures temperature, salinity, and velocity. Hourly surface meteorological data are archived at WHOI (http://uop.whoi.edu/projects/Stratus/stratus.htm), arriving within hours of when it was observed. These data are exchanged in near real time with ECMWF and NCEP; they in turn provide operational data at the model grid point nearest the buoy. It is also shared with the Chilean Navy (SHOA). The same data are shared with CLIVAR investigators, especially modelers interested in the Stratus region and VAMOS/VOCALS investigators in the U.S. and in South America. This meteorological data are used to assess the realism of operational atmospheric models in the stratus region. Once per minute as well as hourly surface meteorological time series are provided to the VOCALS and other investigator communities (including Sandra Yuter, Chris Bretherton, Meghan Cronin) after recovery. The surface meteorological data have been made available to the satellite community (including radiation – Langley, winds – Remote Sensing Systems and JPL, SST – Dick Reynolds, all variables – the SEAFLUX project).

The oceanographic data are being used by Weller at WHOI to investigate air-sea coupling and upper ocean variability under the stratus deck. The initial archive is maintained by the Upper Ocean Processes Group at WHOI, which runs a public access server for their mooring data. The data are also available from OceanSITES (http://www.oceansites.org). We are collaborating with the Baseline Surface Radiation Network (BSRN) and the GEWEX (Global Energy and Water Cycle Experiment) Radiation Panel. Long time series of incoming radiation along with the other coincident surface meteorological observations are very rare in the open ocean. The accuracy of the ORS radiation data has made them of high value for development of improved estimates of surface radiation fields over the oceans.

The Stratus ORS has been occupied since October 2000. We are now able (see Table II-1, for example) to show how far climatological means of the air-sea fluxes, such as those computed from the 40-year ECMWF reanalysis (ERA-40), are incorrect in their representation of the atmosphere-ocean coupling under the very important stratus deck region off northern Chile. The ocean there receives more heat than ERA-40 suggests but the sky is cloudier (lower mean shortwave) than ERA-40 suggests. The additional gain comes from the observed latent, sensible, and longwave heat fluxes being smaller than indicated by the ERA-40 climatology. As an example of our collaboration with modeling centers, ECMWF retrieves our buoy data and does offline runs of modifications of the their atmospheric model to explore how to improve the realism of their model under the stratus clouds.

Variable	Stratus 1	Stratus 2	Stratus 3	Stratus 4	Stratus 5	ECMWF
Latent	-103.1	-118.0	-107.3	-99.0	-99.5	-124.6
Sensible	-7.0	-10.3	-7.1	-7.1	-5.0	-15.2
Longwave	-40.6	-49.2	-36.6	-21.7	-44.6	-55.0
Shortwave	202.0	199.5	190.4	191.3	183.5	220.2
Net	51.4	22.1	39.4	63.4	34.3	25.5

Table II-1: Year-long means of the latent, sensible, longwave, shortwave, and net heat fluxes (net is the sum of the first four, where a positive sign indicates the ocean is being heated) from the first 5 deployments of the Stratus ORS compared to the 40-year mean ECMWF reanalysis values of these heat fluxes.

That models need to be improved is evident in Figure II-1, a comparison of the daily-averaged incoming shortwave radiation climatology (average of six years of data) with the incoming shortwave radiation climatology from ERA-40 (ECMWF 40-year reanalysis) and NCEP-2 (National Center for Environmental Prediction reanalysis). During October to December, the models produce too few clouds, and as a consequence supply too much insolation to the sea surface, with the error close to 50 W m^{-2}.

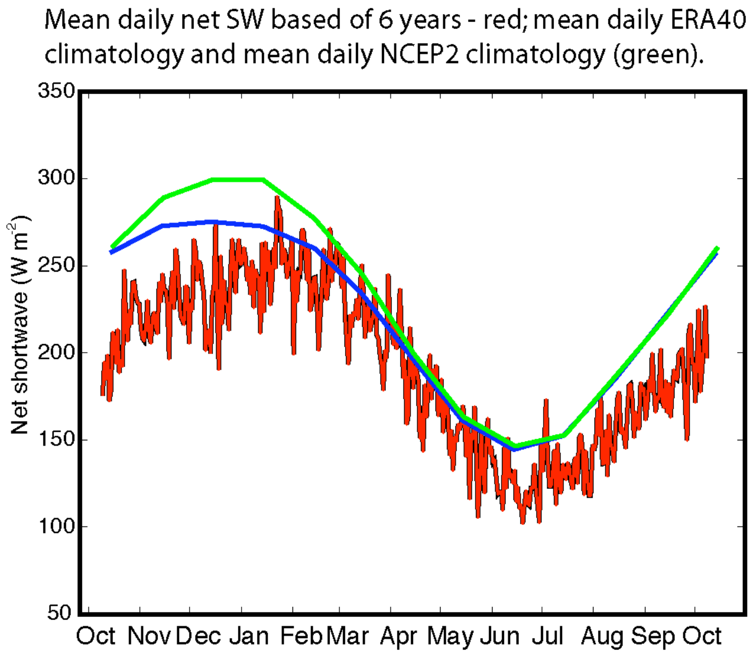

Figure II-1. Comparison of observed incoming shortwave radiation at the Stratus Ocean Reference Station (mean daily, averaged over 6 years, in red) with the monthly climatological incoming shortwave radiation from ERA40 (blue) and NCEP2 (green).

The Stratus cruises serve the wider scientific community by providing a platform on which to study the regional ocean. Additional researchers who participated in collaborative research or benefited from shared ship time in FY2008 have come from many institutions: NOAA Earth System Research Laboratory, Servicio Hydrografico y Oceanografico de la Armada (SHOA, Chile), the NOAA National Data Buoy Center), INOCAR (Institute of Naval Oceanography, Ecuadorian Navy), the Argo float program, the NOAA surface drifter program, Gerard Eldin (France), the Peruvian Navy Hydrographic Service, and IMARPE (Institute of Marine Research, Peru). Ten Argo floats, 13 surface drifters, and 4 French profiling floats were deployed during the cruise. A new NDBC DART buoy was deployed. Weller applied for sampling clearance from Ecuador and Peru, and during the transit this year from Rodman, Panama, sampling was done in collaboration with these countries to investigate the La Niña event then underway. The 2007 Stratus cruise also hosted a teacher from NOAA's Teachers-at-Sea program (Meghan O'Leary). The work this year included recovering and redeploying the WHOI meteorological sensors on the Chilean Navy tsunami warning buoy at 20°S, 75°W; this tsunami warning installation was installed in 2006 with WHOI meteorological sensors on the surface buoy and ocean sensors on the mooring line. The deployment marked the beginning of a growing partnership between the ORS project and SHOA. We serviced self-recording ASIMET modules on the tsunami buoy and temperature and temperature/salinity recorders on the buoy's mooring line (Fig. II-2).

Figure II-2: Chilean Navy (SHOA) DART buoy equipped with WHOI meteorological sensors. Shown here the nternally recording sensor modules being recovered and replaced with fresh modules in October 2007.

Task III: NTAS Site:

The Northwest Tropical Atlantic Station (NTAS) project for air-sea flux measurement was conceived in order to investigate surface forcing and oceanographic response in a region of the tropical Atlantic with strong SST anomalies and the likelihood of significant local air-sea interaction on seasonal to decadal time scales. The strategy is to maintain a meteorological measurement station at approximately 15° N, 51° W through successive (annual) turn-arounds of a surface mooring. Redundant meteorological systems measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas.

NTAS has two primary science objectives: 1) Determine the air-sea fluxes of heat, moisture and momentum in the northwest tropical Atlantic using high-quality, in-situ meteorological measurements from a moored buoy. 2) Compare the in-situ fluxes to those available from operational models and satellites, identify the flux components with the largest discrepancies, and investigate the reasons for the discrepancies. An ancillary objective is to compute the local (one-dimensional) oceanic budgets of heat and momentum and determine the degree to which these budgets are locally balanced.

A mooring turn-around cruise was conducted on the NOAA ship *Ronald H. Brown* in April 2007 in order to retrieve the existing mooring (NTAS-6, deployed 25 February 2006) and replace it with a new mooring (NTAS-7). In preparation for this cruise, three ASIMET systems were calibrated and tested, and two systems, comprised of the best performing sensors, were prepared for deployment. The NTAS-7 mooring was deployed on 19 April 2007 and the NTAS-6 mooring was recovered on 24 April. The period between deployment and recovery was dedicated to a comparison of the two buoy systems, with the shipboard system as an independent benchmark. Data return was very good, with all meteorological sensors showing complete records except for wind, for which one system had 97% return. Since the second system had a complete wind record, no data will be missing in the final (combined) data set.

The 2007 NTAS cruise represented the second year of collaboration with the National Data Buoy Center (NDBC) and the first year of collaboration with the

Meridional Overturning Variability Experiment (MOVE). NDBC operations included servicing sensors and electonics on the 41041 "Middle Atlantic" buoy (Fig. III-1), recovery of a subsurface telemetry mooring deployed in 2006 at the 41042 site, and deployment of a replacement mooring at the same site. The MOVE effort involved deployment of four Pressure/Inverted Echo Sounders (PIES; Fig. III-1). Three PIES were deployed at sites between Guadeloupe and the NTAS mooring, and one was deployed southeast of Barbados. Three Argo floats were deployed during the cruise at the request of NOAA AOML. A novel drifter designed by J. Boyle of W. Connecticut State U. to measure heat transfer across the air-sea interface was deployed in the vicinity of the NTAS buoy as part of an engineering field test.

Figure III-1. NDBC personnel in the midst of servicing operations on the 6-meter NOMAD buoy at Station 41041 (left). Deployment of Pressure/Inverted Echo Sounder (PIES) sensor by C. Begler of Scripps as part of MOVE operations (right).

A unique aspect of the NTAS-7 cruise was an Education and Outreach program done in cooperation with the Joint Oceanographic Institutions (JOI). JOI Program Assistants Jessica Sharoff and Karinna Sjo-Gaber created a "live", interactive web site documenting the seagoing experience. The site had content for media, museums, teachers, and elementary to high school students. The outreach effort was successful, with an estimated 2,300 first-time visitors to the site during the cruise, along with 4 press releases, 4 newspaper articles, 15 web links from other sites, and an article in WHOI's online magazine *Oceanus*. The site was archived at JOI after the cruise, and can be viewed at http://joiserver.joiscience.org/mission1551.

NTAS surface meteorological data are archived on the UOP web site (http://uop.whoi.edu/projects/NTAS/ntas.htm) and also available in near real time from the NDBC web server (http://www.ndbc.noaa.gov). Data are exchanged with ECMWF and NCEP, and they in turn provide operational model output at the grid point nearest the buoy. NTAS data are also available through OceanSITES (http://www.oceansites.org) and are shared with the Baseline Surface Radiation Network (BSRN) and the GEWEX (Global Energy and Water Cycle Experiment) Radiation Panel.

A major engineering initiative this year was the implementation of an inductive telemetry system on the NTAS mooring to collect and telemeter data in near-real time from subsurface instruments. An electro-mechanical (EM) interface was developed (Fig. III-2), including a specially designed universal joint, a six-meter electro-mechanical “compliant section”, and a wire coupling assembly with a bell mouth and socket to accept a specially terminated shot of 7/16” jacketed mooring wire. A communications subsystem was developed to support inductive telemetry. The system was built around an ASIMET controller board, and included a Seabird Inductive Modem and a custom built Iridium communication module. The controller polls addresses on the inductive loop and places sensor data, obtained at 5 to 15 minute intervals, in a buffer. After 4 hours the Iridium module obtains the buffered data, creates and logs 4 one-hour averages, formats the averages as a Short Burst Data (SBD) message, and sends the SBD message via Iridium.

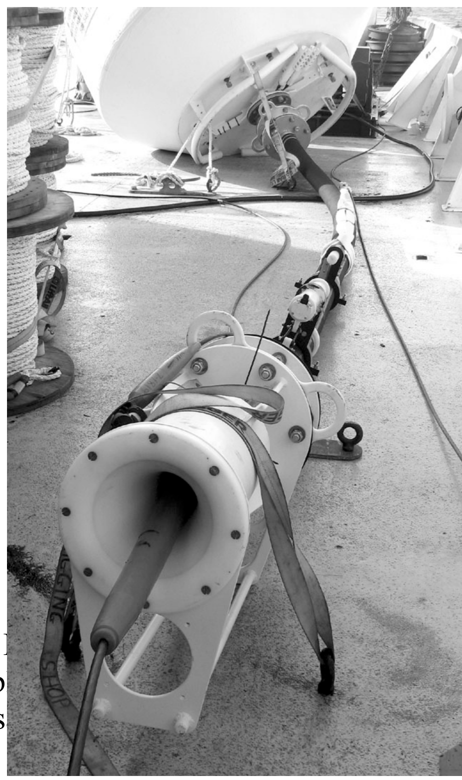

Figure I ... ar
assemb ... ut on deck and connected to the buoy (left), univers ... pper right), lower flanged spacer and wire-

For the telemetry trial on NTAS-7, the mooring line was outfitted with four instruments from the UOP inventory which contained inductive modems: Three Seabird SBE-37s at 25, 45 and 65 m and a Sontek Argonaut current meter 14 m. The telemetered message is a subset of the data returned from inductive polling. For example, only temperature and conductivity (later converted to salinity) are transmitted from the SBE-37s, and the Argonaut data record is reduced to just 8 variables. The inductive coupler on the current meter failed soon after deployment, but temperature and salinity data are being obtained routinely and are available from the UOP web site. (Fig. III-3).

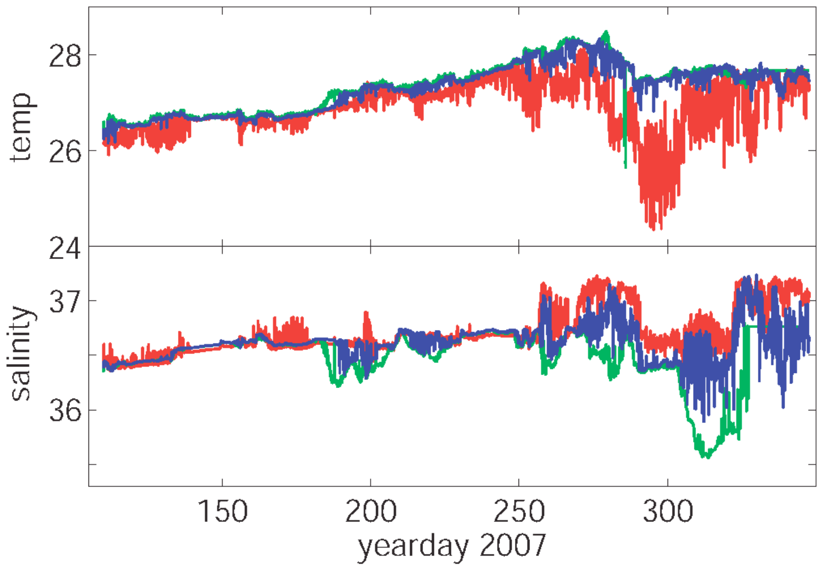

Figure III-3. NTAS-7 subsurface temperature (upper) and salinity (lower) at 25 m (red), 45 m (green), and 65 m (blue) depth from inductive telemetry system (obtained and plotted in December 2007 from the UOP web site).

Task IV: Hawaii Site:

The Hawaii Ocean Time-series (HOT) site, 100 km north of Oahu, Hawaii, has been occupied since 1988 as a part of the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). Among the HOT science goals are to document and understand seasonal and interannual variability of water masses, relate water mass variations to gyre fluctuations, and develop a climatology of high-frequency physical variability in the context of interdisciplinary time series studies. The primary intent of the WHOI Hawaii Ocean Timeseries Station (WHOTS) mooring is to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, fresh water and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. It is expected that establishment of the WHOTS mooring will accelerate progress toward understanding multidisciplinary science at the site, provide an anchor site for developing air-sea flux fields in the Pacific, and provide a new regime in which to examine atmospheric, oceanic, and coupled model performance as well as the performance of remote sensing methods.

The observational strategy is to maintain a surface mooring at approximately 22.75° N, 158° W, instrumented to obtain meteorological and upper ocean measurements, through successive (annual) turnarounds done in cooperation with HOT investigators. Redundant meteorological systems on the surface buoy measure the variables necessary to compute air-sea fluxes of heat, moisture and momentum using bulk aerodynamic formulas. Subsurface oceanographic sensors on the mooring are being provided through cooperation with Roger Lukas (U. Hawaii; funded by the National Science Foundation).

A mooring turn-around cruise was conducted in June 2007 on the U. Hawaii ship *Kilo Moana*. The field work was done in cooperation with Roger Lukas and other HOT investigators from U. Hawaii. In preparation for this cruise, three ASIMET systems were assembled and tested. The WHOTS-4 mooring was deployed on 25 June 2006 and the WHOTS-3 mooring was recovered on 28 June. The period between deployment and recovery was dedicated to a comparison of the two buoy systems, with the shipboard system as an independent benchmark. The standard *Kilo Moana* meteorological sensors were complemented by installation of a UOP AutoIMET system similar to that used on Volunteer Observing Ships. Data return from the two WHOTS-3 ASIMET systems was very good, with only one significant failure – one of the precipitation sensors failed four days prior to deployment. The remaining sensors operated for the full 368 day deployment.

The WHOTS-2 and WHOTS-3 moorings were used as test-beds for Iridium data telemetry systems developed under the ORS Engineering, Oversight and Data task. Both systems performed well, and the electronics from WHOTS-2 were used as the basis for the NTAS-7 subsurface telemetry system. The electronics deployed on WHOTS-3 will be dedicated to an NTAS-8 subsurface telemetry implementation. Thus, the WHOTS-4 buoy reverted to standard Argos telemetry without an Iridium system.

Commercial bird barrier strips were installed on the WHOTS-3 buoy to reduce data contamination and sensor shadowing due to birds and their accompanying guano deposition. Evaluation of the buoy prior to and after recovery indicated that the prevention efforts were largely successful, little evidence of birds having perched on the on the tower and sensors. The same barrier strips were installed on the WHOTS-4 buoy.

In cooperation with C. Sabine and S. Maenner of PMEL, and with the assistance of D. Sadler (U. Hawaii), a pCO2 system was incorporated in the WHOTS-4 buoy (Fig IV-1).

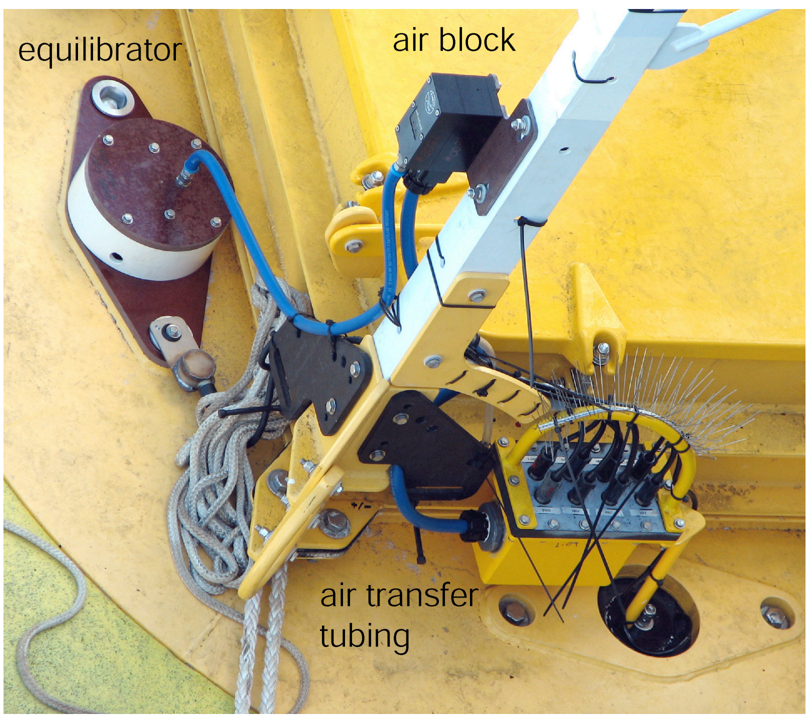

Figure IV-1. Principal external components of pCO2 system on the WHOTS-4 buoy. The equilibrator tube extends through a hole in the foam hull into the water below. Air transfer tubing within a protective conduit (blue) connects the equilibrator to the air block and the air block to instrumentation inside the buoy well.

Incorporation of CO_2 measurements on the WHOTS buoy provided continuation of the time series begun in 2004 from the MOSEAN buoy. CO_2 measurements are made every three hours in ambient air and in air equilibrated with surface seawater using an infra-red detector. A summary file of the measurements is transmitted once per day and plots of the data are posted in near real-time to the web. To view the daily data visit the NOAA PMEL Moored CO_2 Website: http://www.pmel.noaa.gov/co2/moorings/hot/hot_main.htm. Within a year of system recovery, the final processed data are submitted to the Carbon Dioxide Information Analysis Center (CDIAC).

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